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Internal Assesment Test –I

Sub:	Transformers & Generators (T&G)							Code:	18EE33
Date:	07/09/2019	Duration:	90 mins	Max Marks:	50	Sem:	3rd	Branch:	EEE

Answer any five full questions. Sketch figures wherever necessary.

		Marks	OBE	
			CO	Level
1	Explain operation of practical transformer. Draw and explain the Full load Phasor Diagrams of Single Phase transformer for lagging, leading and Unity power factor loads	10	CO1	L1
2.a	A 4 KVA ,200/400V Single phase Transformer supplying full load current of 0.8pf lagging The OC & SC test results are : OC Test:200V,0.8A,70W SC Test 20V,10A,60W(LV Side) i) Calculate efficiency and secondary voltage	07	CO1	L3
2.b	What is all day efficiency of transformer? How to calculate it?	03	CO1	L1
3	A 20kVA, 2200/220V, 50Hz single phase transformer gave the following readings: OC test:- 220V, 4.2A, 148W (HV side open) SC test:- 86V, 10.5A, 360W (LV side shorted) Determine (i) The equivalent resistance and reactance referred to the secondary, (ii) The voltage regulation on full load 0.8pf lagging, (iii) Efficiency at full load and half the full load at 0.8 pf lagging.	10	CO1	L3
4 a	List the advantages of single 3- phase unit transformer over bank of single phase transformers	03	CO1	L1
4 b	With a neat circuit diagram explain in detail sumpner's test for determining the efficiency and voltage regulation of transformer	07	CO1	L1
5 a	List the conditions to be satisfied for satisfactory parallel operation of both single phase and three phase transformers.	05	CO2	L3
5 b	Derive an expression for the currents shared by between two transformers connected in parallel supplying a common load when no load voltages of these transformers are unequal.	05	CO2	L3
6 a	With the help of phasor diagram explain how two phase supply can be obtained using three phase supply	06	CO1	L3
6 b	Find the all day efficiency of a transformer having maximum efficiency of 98% at 15 KVA at upf and loaded as follows : 2 KW at 0.5 pf lag for 12 Hrs 12 KW at 0.8 pf lag for 6 Hrs No load for 6 Hrs.	04	CO1	L3
7	Define regulation and obtain regulation equation for both leading and lagging power factor of a single phase transformer.	10	CO1	L2

*******All the Best******

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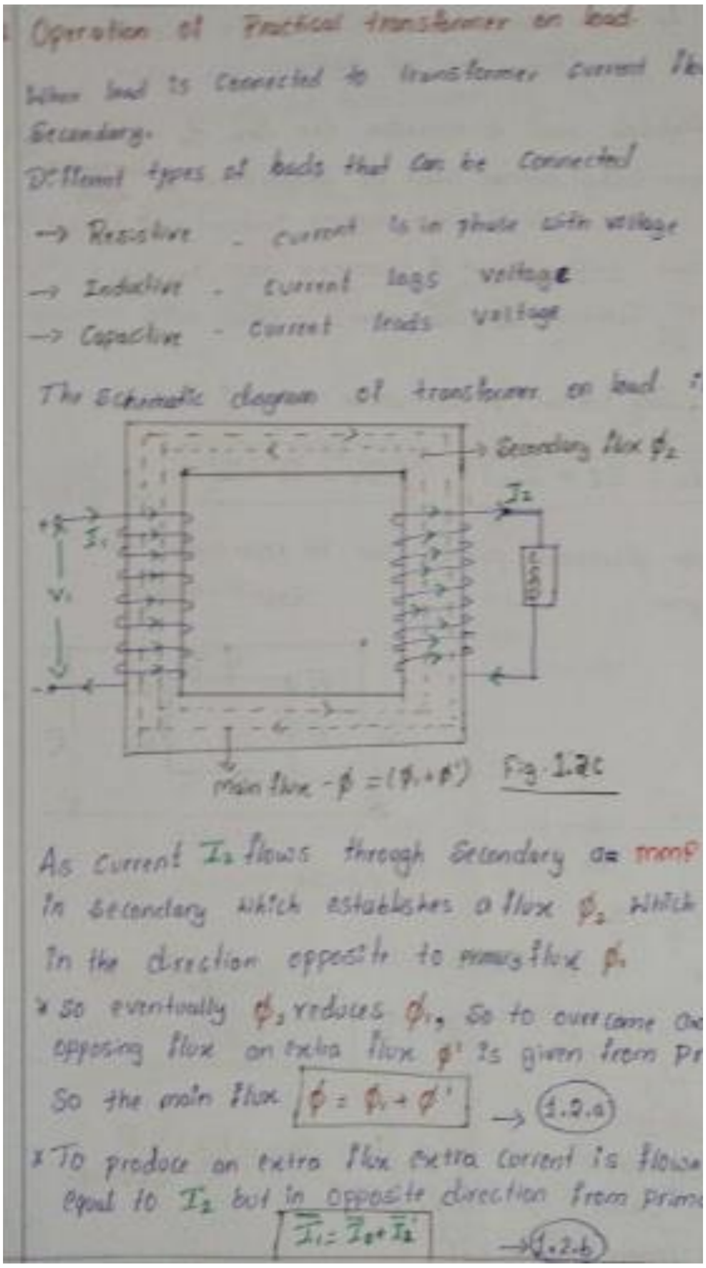
Solution

1



Operation of Practical transformer on load

When load is connected to transformer current fl

Secondary.

Different types of loads that can be connected

→ Resistive - current is in phase with voltage

→ Inductive - current lags voltage

→ Capacitive - current leads voltage

The schematic diagram of transformer on load i

main flux - $\phi = (\phi_1 + \phi')$ Fig. 1.2c

As current I_2 flows through secondary a mmf

in secondary which establishes a flux ϕ_2 which

in the direction opposite to primary flux ϕ_1

* so eventually ϕ_2 reduces ϕ_1, so to overcome the

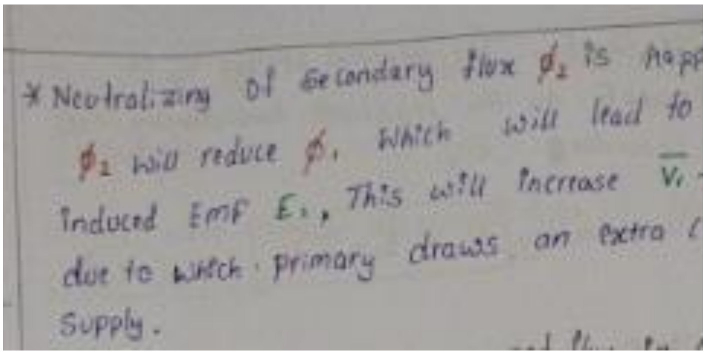
opposing flux an extra flux ϕ' is given from Pr

So the main flux $\boxed{\phi = \phi_1 + \phi'}$ → (1.2.a)

* To produce an extra flux extra current is flow

equal to I_2 but in opposite direction from prim

$\boxed{\overline{I_1} = \overline{I_0} + \overline{I_2'}}$ → (1.2.b)



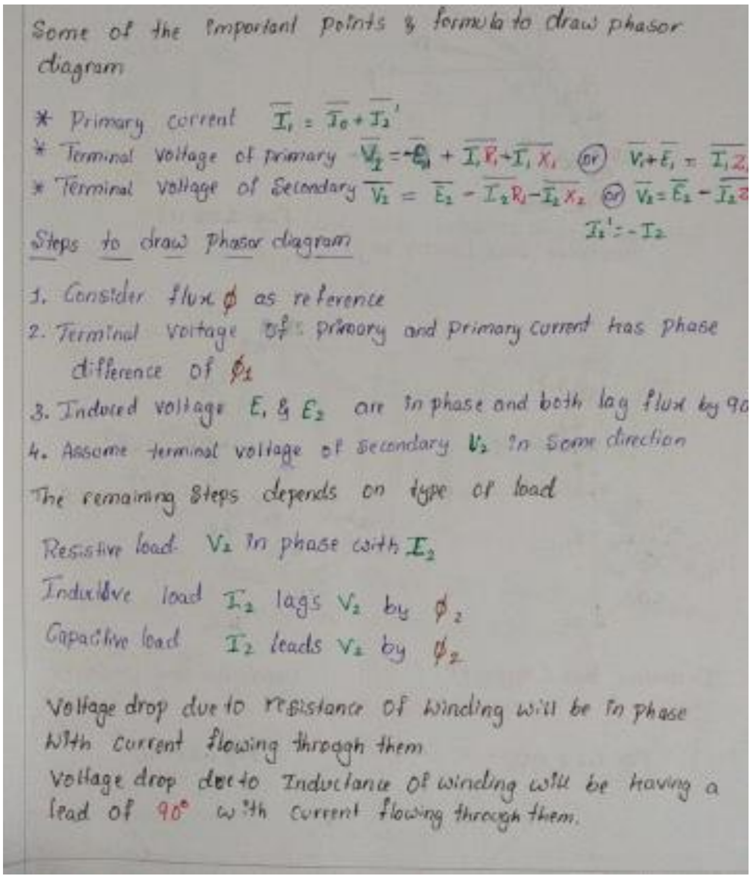
* Neutralizing of secondary flux ϕ_2 is happ

ϕ_2 will reduce ϕ_1, which will lead to

Induced EMF E_1, This will increase $\overline{V_1}$ -

due to which primary draws an extra c

supply.



Some of the important points & formula to draw phasor diagram

* Primary current $\overline{I_1} = \overline{I_0} + \overline{I_2}'$
* Terminal voltage of primary $\overline{V_1} = -\overline{E_1} + \overline{I_1 R_1} + \overline{I_1 X_1}$ (or) $\overline{V_1} + \overline{E_1} = \overline{I_1 Z}$
* Terminal voltage of secondary $\overline{V_2} = \overline{E_2} - \overline{I_2 R_2} - \overline{I_2 X_2}$ (or) $\overline{V_2} = \overline{E_2} - \overline{I_2}$

$I_2' = -I_2$

Steps to draw phasor diagram

1. Consider flux ϕ as reference
2. Terminal voltage of primary and primary current has phase difference of ϕ_1
3. Induced voltage E_1 & E_2 are in phase and both lag flux by 90
4. Assume terminal voltage of secondary V_2 in some direction

The remaining steps depends on type of load

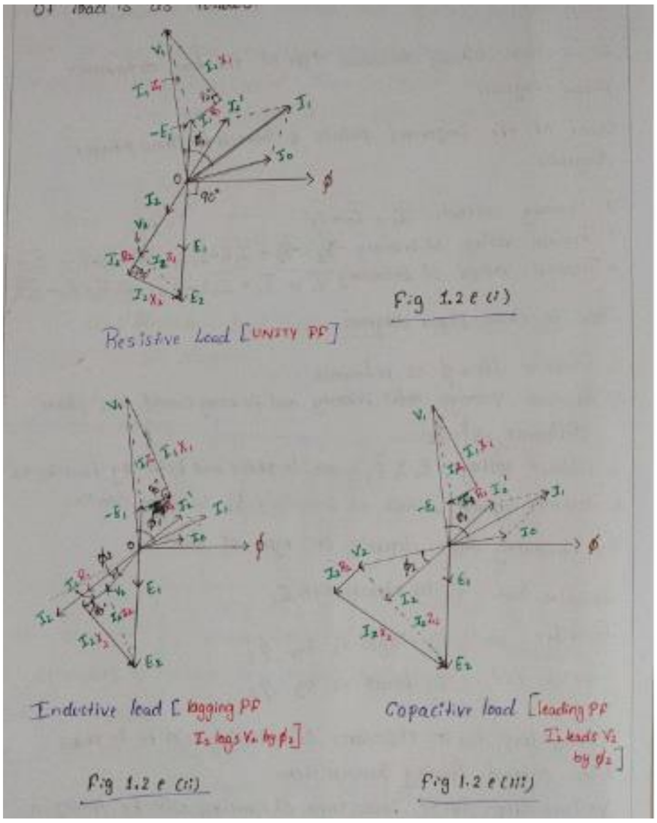
Resistive load V_2 in phase with I_2

Inductive load I_2 lags V_2 by ϕ_2

Capacitive load I_2 leads V_2 by ϕ_2

Voltage drop due to resistance of winding will be in phase with current flowing through them

Voltage drop due to inductance of winding will be having a lead of 90° with current flowing through them.



Resistive Load [UNITY PF]

Fig 1.2 e (i)

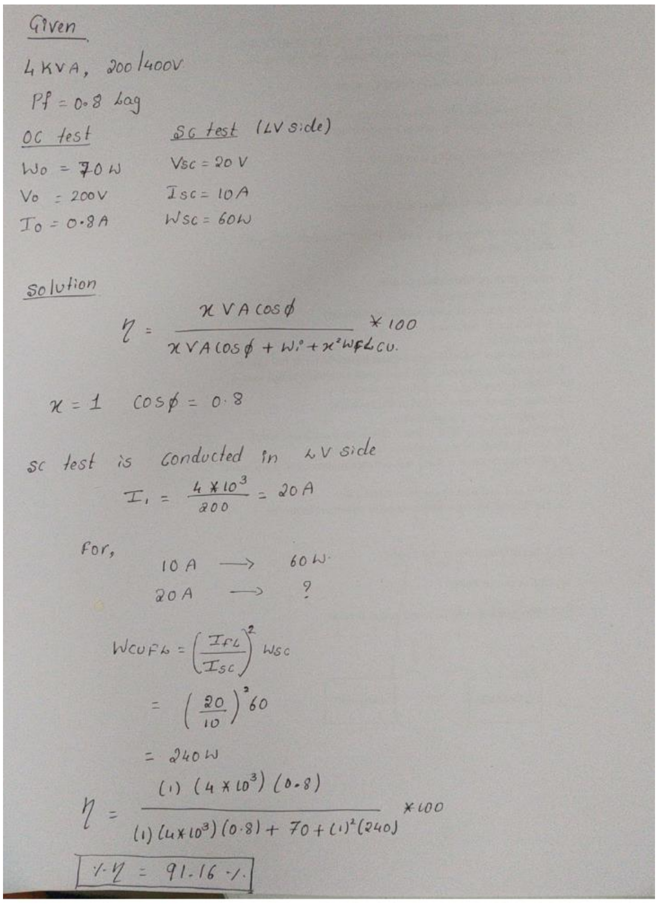
Inductive load [lagging PF I_2 lags V_2 by ϕ_2]

Fig 1.2 e (ii)

Capacitive load [leading PF I_2 leads V_2 by ϕ_2]

Fig 1.2 e (iii)

2 a



Given

4 KVA, 200/400V

Pf = 0.8 lag

OC test	SC test (LV side)
$W_o = 70\,W$	$V_{sc} = 20\,V$
$V_o = 200\,V$	$I_{sc} = 10\,A$
$I_o = 0.8\,A$	$W_{sc} = 60\,W$

Solution

$$\eta = \frac{x\,VA\cos\phi}{x\,VA\cos\phi + W_i + x^2 W_{FL\,cu}} * 100$$

$x = 1 \quad \cos\phi = 0.8$

SC test is conducted in LV side

$$I_1 = \frac{4 * 10^3}{200} = 20\,A$$

For,

$10\,A \longrightarrow 60\,W$

$20\,A \longrightarrow\ ?$

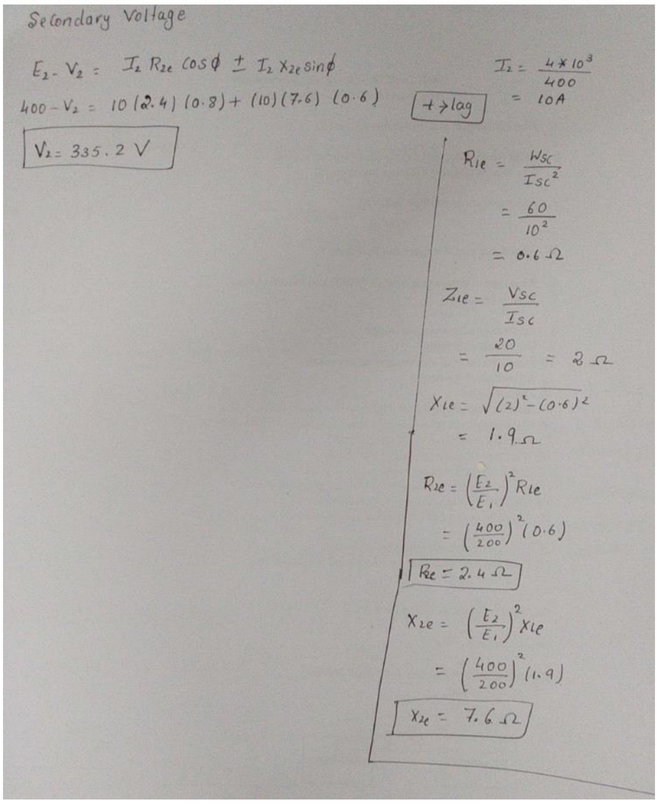
$$W_{cuFL} = \left(\frac{I_{FL}}{I_{sc}}\right)^2 W_{sc}$$

$$= \left(\frac{20}{10}\right)^2 60$$

$$= 240\,W$$

$$\eta = \frac{(1)\,(4 * 10^3)\,(0.8)}{(1)(4*10^3)(0.8) + 70 + (1)^2(240)} * 100$$

$$\boxed{\%\,\eta = 91.16\,\%}$$



Secondary Voltage

$$E_2 - V_2 = I_2 R_{2e}\cos\phi \pm I_2 X_{2e}\sin\phi$$

$$400 - V_2 = 10\,(2.4)\,(0.8) + (10)(7.6)\,(0.6)$$

$\boxed{+ \rightarrow lag}$

$$I_2 = \frac{4*10^3}{400} = 10\,A$$

$$\boxed{V_2 = 335.2\,V}$$

$$R_{1e} = \frac{W_{sc}}{I_{sc}^2} = \frac{60}{10^2} = 0.6\,\Omega$$

$$Z_{1e} = \frac{V_{sc}}{I_{sc}} = \frac{20}{10} = 2\,\Omega$$

$$X_{1e} = \sqrt{(2)^2 - (0.6)^2} = 1.9\,\Omega$$

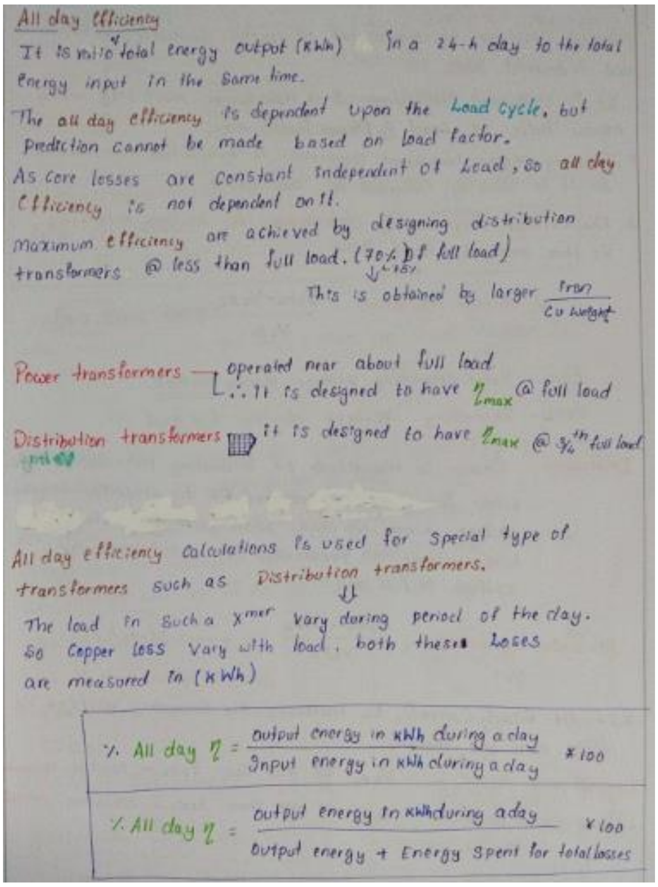
$$R_{2e} = \left(\frac{E_2}{E_1}\right)^2 R_{1e} = \left(\frac{400}{200}\right)^2 (0.6)$$

$$\boxed{R_{2e} = 2.4\,\Omega}$$

$$X_{2e} = \left(\frac{E_2}{E_1}\right)^2 X_{1e} = \left(\frac{400}{200}\right)^2 (1.9)$$

$$\boxed{X_{2e} = 7.6\,\Omega}$$

2 b



All day Efficiency

It is ratio of total energy output (KWh) in a 24-h day to the total Energy input in the same time.

The all day efficiency is dependent upon the Load cycle, but prediction cannot be made based on load factor.

As core losses are constant independent of Load, so all day Efficiency is not dependent on it.

Maximum efficiency are achieved by designing distribution transformers @ less than full load. (70% of full load)
↓ 75%
This is obtained by larger $\frac{Iron}{Cu\ weight}$

Power transformers — operated near about full load
∴ It is designed to have η_{max} @ full load

Distribution transformers It is designed to have η_{max} @ 3/4th full load

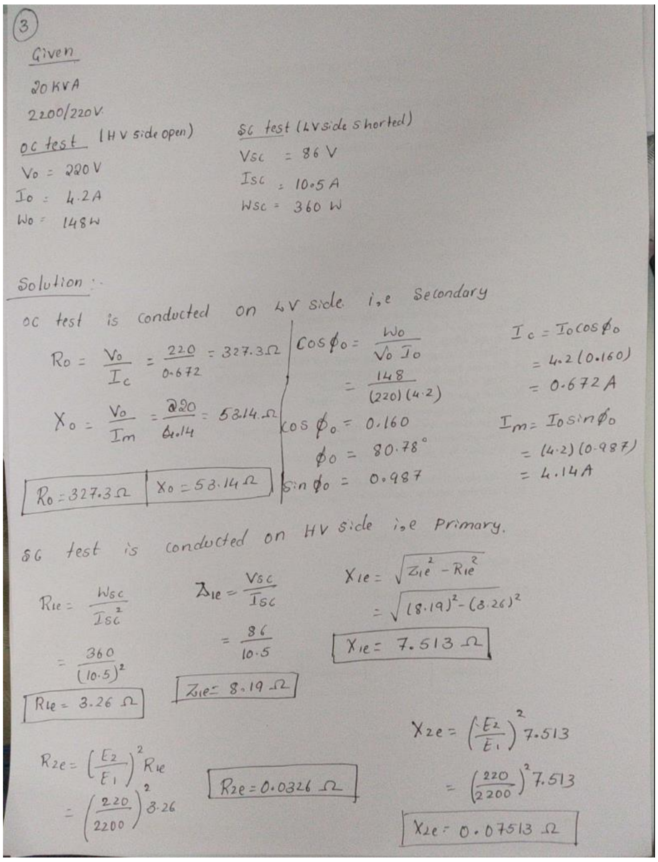
[illegible]

All day efficiency calculations is used for special type of transformers such as Distribution transformers.
⇓
The load in such a x^{mer} vary during period of the day. So Copper loss vary with load, both these Loses are measured in (KWh)

$$\%\ \text{All day}\ \eta = \frac{\text{output energy in KWh during a day}}{\text{Input energy in KWh during a day}} * 100$$

$$\%\ \text{All day}\ \eta = \frac{\text{output energy in KWh during a day}}{\text{output energy + Energy spent for total losses}} * 100$$

3



③

Given

20 KVA

2200/220V

OC test (HV side open)	SC test (LV side shorted)
$V_o = 220\,V$	$V_{sc} = 86\,V$
$I_o = 4.2\,A$	$I_{sc} = 10.5\,A$
$W_o = 148\,W$	$W_{sc} = 360\,W$

Solution :

OC test is conducted on LV side i,e Secondary

$$R_o = \frac{V_o}{I_c} = \frac{220}{0.672} = 327.3\,\Omega$$

$$X_o = \frac{V_o}{I_m} = \frac{220}{4.14} = 53.14\,\Omega$$

$$\boxed{R_o = 327.3\,\Omega} \quad \boxed{X_o = 53.14\,\Omega}$$

$$\cos\phi_o = \frac{W_o}{V_o I_o} = \frac{148}{(220)(4.2)}$$

$\cos\phi_o = 0.160$

$\phi_o = 80.78°$

$\sin\phi_o = 0.987$

$$I_c = I_o\cos\phi_o = 4.2\,(0.160) = 0.672\,A$$

$$I_m = I_o\sin\phi_o = (4.2)(0.987) = 4.14\,A$$

SC test is conducted on HV side i,e Primary.

$$R_{1e} = \frac{W_{sc}}{I_{sc}^2} = \frac{360}{(10.5)^2}$$

$$\boxed{R_{1e} = 3.26\,\Omega}$$

$$Z_{1e} = \frac{V_{sc}}{I_{sc}} = \frac{86}{10.5}$$

$$\boxed{Z_{1e} = 8.19\,\Omega}$$

$$X_{1e} = \sqrt{Z_{1e}^2 - R_{1e}^2} = \sqrt{(8.19)^2 - (3.26)^2}$$

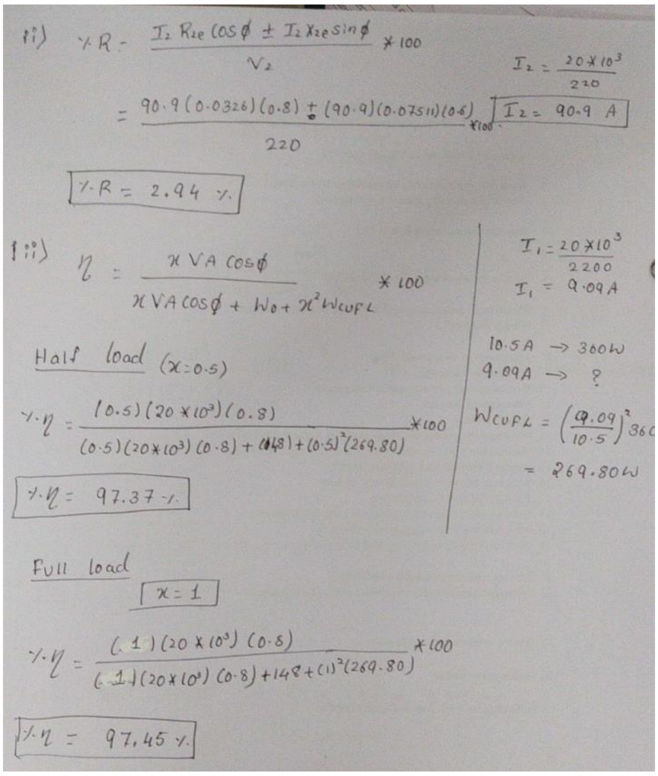
$$\boxed{X_{1e} = 7.513\,\Omega}$$

$$R_{2e} = \left(\frac{E_2}{E_1}\right)^2 R_{1e} = \left(\frac{220}{2200}\right)^2 3.26$$

$$\boxed{R_{2e} = 0.0326\,\Omega}$$

$$X_{2e} = \left(\frac{E_2}{E_1}\right)^2 7.513 = \left(\frac{220}{2200}\right)^2 7.513$$

$$\boxed{X_{2e} = 0.07513\,\Omega}$$



ii) $\% R = \frac{I_2 R_{2e} \cos\phi \pm I_2 X_{2e} \sin\phi}{V_2} \times 100$

$I_2 = \frac{20 \times 10^3}{220}$

$= \frac{90.9(0.0326)(0.8) \pm (90.9)(0.07511)(0.6)}{220} \times 100$

$\boxed{I_2 = 90.9 \text{ A}}$

$\boxed{\% R = 2.94 \%}$

iii) $\eta = \frac{x \, VA \cos\phi}{x \, VA \cos\phi + W_0 + x^2 W_{cuFL}} \times 100$

$I_1 = \frac{20 \times 10^3}{2200}$

$I_1 = 9.09 A$

10.5A → 300W

9.09A → ?

$W_{cuFL} = \left(\frac{9.09}{10.5}\right)^2 36$

$= 269.80 W$

Half load $(x = 0.5)$

$\% \eta = \frac{(0.5)(20 \times 10^3)(0.8)}{(0.5)(20 \times 10^3)(0.8) + (148) + (0.5)^2(269.80)} \times 100$

$\boxed{\% \eta = 97.37 \%}$

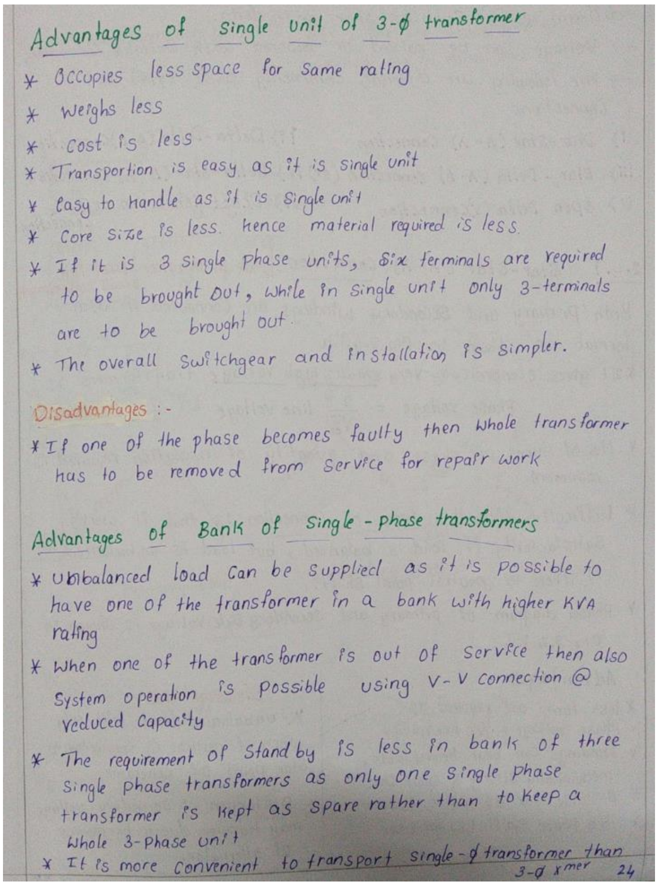
Full load

$\boxed{x = 1}$

$\% \eta = \frac{(1)(20 \times 10^3)(0.8)}{(1)(20 \times 10^3)(0.8) + 148 + (1)^2(269.80)} \times 100$

$\boxed{\% \eta = 97.45 \%}$

4 a



Advantages of single unit of 3-ϕ transformer

- * Occupies less space for same rating
- * Weighs less
- * Cost is less
- * Transportion is easy as it is single unit
- * Easy to handle as it is single unit
- * Core size is less. hence material required is less.
- * If it is 3 single phase units, six terminals are required to be brought out, while in single unit only 3-terminals are to be brought out
- * The overall switchgear and installation is simpler.

Disadvantages :-

- * If one of the phase becomes faulty then whole transformer has to be removed from service for repair work

Advantages of Bank of single - phase transformers

- * Unbalanced load can be supplied as it is possible to have one of the transformer in a bank with higher KVA rating
- * When one of the transformer is out of service then also system operation is possible using V-V connection @ reduced capacity
- * The requirement of stand by is less in bank of three single phase transformers as only one single phase transformer is kept as spare rather than to keep a whole 3-phase unit
- * It is more convenient to transport single-ϕ transformer than 3-ϕ xmer

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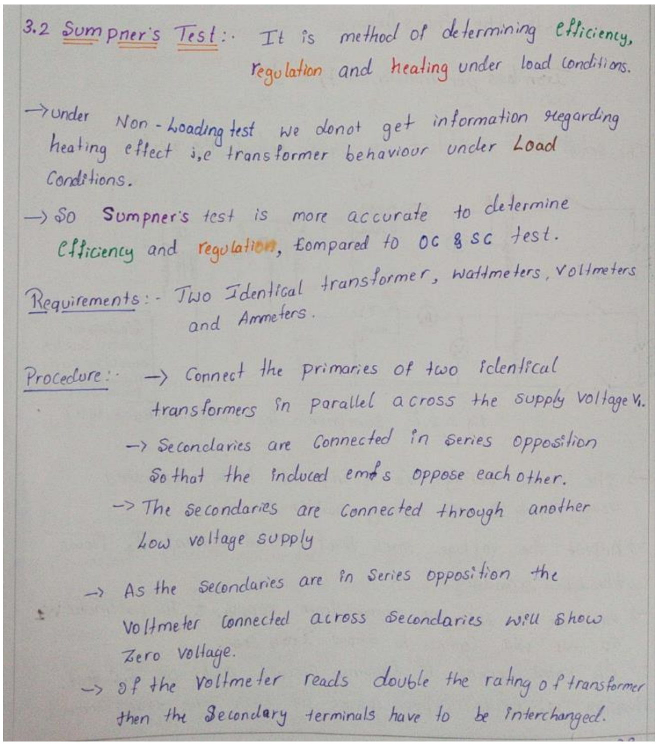
4 b



3.2 Sumpner's Test :- It is method of determining efficiency, regulation and heating under load conditions.

→ Under Non-Loading test we donot get information regarding heating effect i,e transformer behaviour under Load Conditions.

→ So Sumpner's test is more accurate to determine efficiency and regulation, compared to OC & SC test.

Requirements :- Two Identical transformer, wattmeters, voltmeters and Ammeters.

Procedure :-

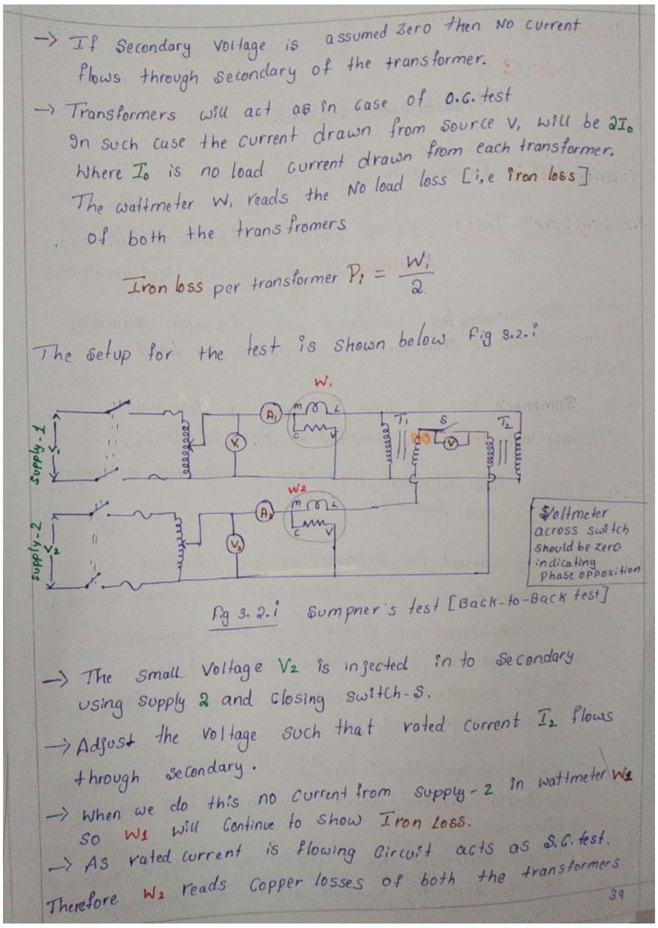
→ Connect the primaries of two identical transformers in parallel across the supply voltage V_1.

→ Secondaries are connected in series opposition so that the induced emf's oppose each other.

→ The secondaries are connected through another low voltage supply

→ As the secondaries are in series opposition the voltmeter connected across secondaries will show zero voltage.

→ If the voltmeter reads double the rating of transformer then the secondary terminals have to be interchanged.



→ If secondary voltage is assumed zero then no current flows through secondary of the transformer.

→ Transformers will act as in case of O.C. test

In such case the current drawn from source V_1 will be $2I_0$ from each transformer.

Where I_0 is no load current drawn

The wattmeter W_1 reads the No load loss [i,e iron loss] of both the transfromers

Iron loss per transformer $P_i = \frac{W_1}{2}$

The setup for the test is shown below. Fig 3.2.i

Fig 3.2.i Sumpner's test [Back-to-Back test]

→ The small voltage V_2 is injected in to secondary using supply 2 and closing switch-S.

→ Adjust the voltage such that rated current I_2 flows through secondary.

→ When we do this no current from supply-2 in wattmeter W_1 so W_1 will continue to show Iron Loss.

→ As rated current is flowing circuit acts as S.C. test.

Therefore W_2 reads copper losses of both the transformers

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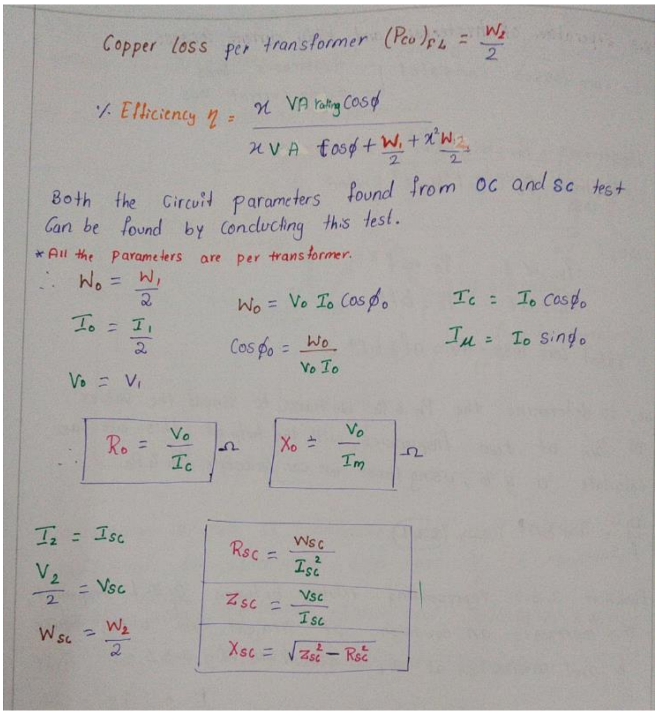


Copper loss per transformer $(P_{cu})_{FL} = \frac{W_2}{2}$

% Efficiency $\eta = \dfrac{x\ \text{VA rating} \cos\phi}{x\,\text{VA} \cos\phi + \frac{W_1}{2} + x^2 \frac{W_2}{2}}$

Both the circuit parameters found from OC and SC test Can be found by conducting this test.

* All the parameters are per transformer.

$\therefore W_0 = \frac{W_1}{2}$ $\qquad W_0 = V_0 I_0 \cos\phi_0$ $\qquad I_c = I_0 \cos\phi_0$

$I_0 = \frac{I_1}{2}$ $\qquad \cos\phi_0 = \frac{W_0}{V_0 I_0}$ $\qquad I_\mu = I_0 \sin\phi_0$

$V_0 = V_1$

$\therefore \boxed{R_0 = \frac{V_0}{I_c}}\ \Omega \qquad \boxed{X_0 = \frac{V_0}{I_m}}\ \Omega$

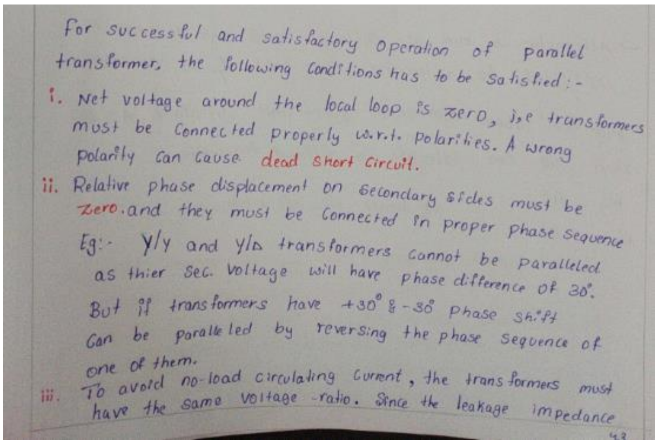
$I_2 = I_{sc}$

$\frac{V_2}{2} = V_{sc}$

$W_{sc} = \frac{W_2}{2}$

$$\boxed{\begin{array}{c} R_{sc} = \dfrac{W_{sc}}{I_{sc}^2} \\ \hline Z_{sc} = \dfrac{V_{sc}}{I_{sc}} \\ \hline X_{sc} = \sqrt{Z_{sc}^2 - R_{sc}^2} \end{array}}$$

5 a



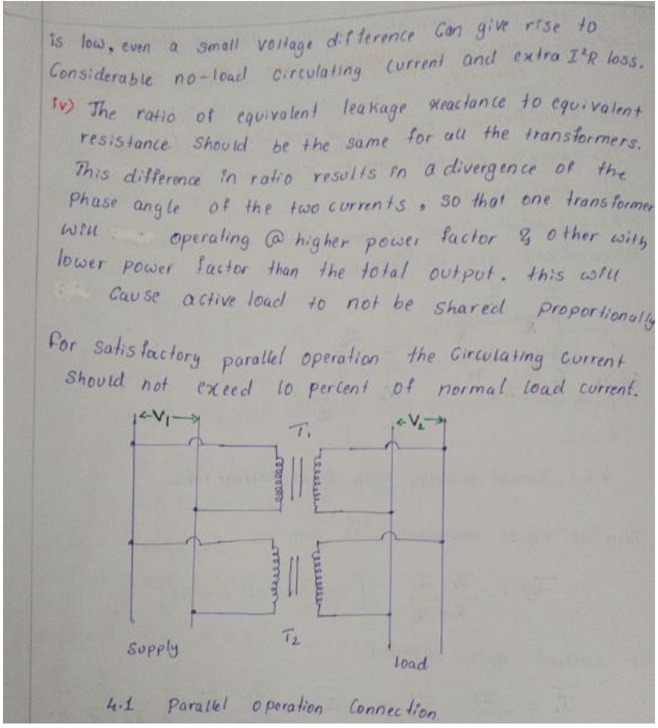
For successful and satisfactory Operation of parallel transformer, the following Conditions has to be Satisfied :-

i. Net voltage around the local loop is zero, i.e transformers must be Connected properly w.r.t. Polarities. A wrong polarity can cause dead short circuit.

ii. Relative phase displacement on secondary sides must be zero. and they must be Connected in proper phase Sequence

Eg:- Y/Y and Y/Δ transformers cannot be paralleled as thier Sec. Voltage will have phase difference of 30°. But if transformers have +30° & -30° phase shift Can be paralleled by reversing the phase sequence of one of them.

iii. To avoid no-load circulating current, the transformers must have the same voltage ratio. Since the leakage impedance



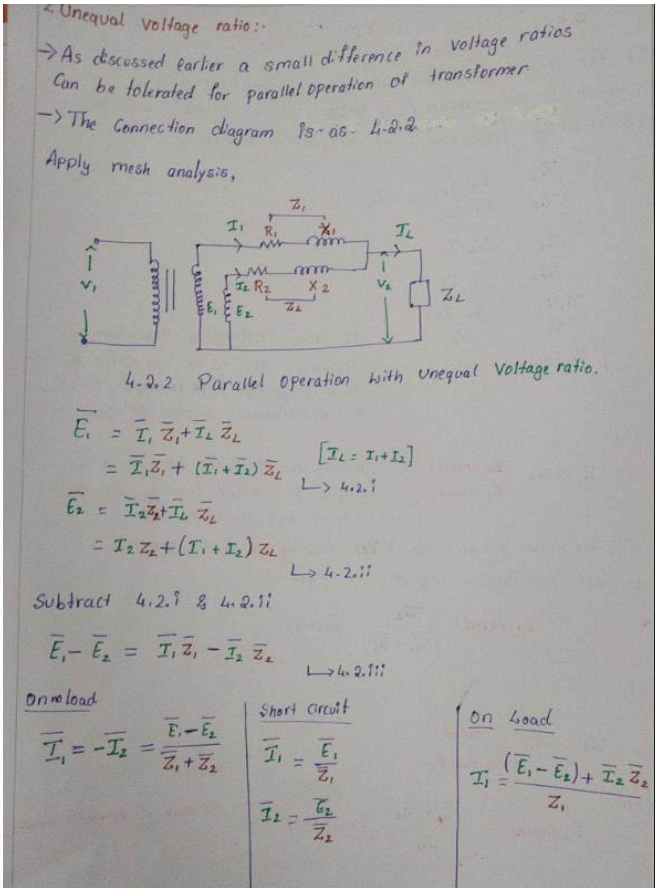
is low, even a small voltage difference Can give rise to Considerable no-load circulating current and extra I^2R loss.

iv) The ratio of equivalent leakage reactance to equivalent resistance should be the same for all the transformers. This difference in ratio results in a divergence of the phase angle of the two currents, so that one transformer will operating @ higher power factor & other with lower power factor than the total output. this will Cause active load to not be shared proportionally

For Satisfactory parallel operation the Circulating current Should not exceed 10 percent of normal load current.

4.1 Parallel operation Connection

5 b



2. Unequal voltage ratio:-

→ As discussed earlier a small difference in voltage ratios Can be tolerated for parallel operation of transformer

→ The Connection diagram is as 4.2.2

Apply mesh analysis,

4.2.2 Parallel operation with unequal Voltage ratio.

$$\bar{E}_1 = \bar{I}_1 \bar{Z}_1 + \bar{I}_L \bar{Z}_L \qquad [I_L = I_1 + I_2]$$

$$= \bar{I}_1 \bar{Z}_1 + (\bar{I}_1 + \bar{I}_2)\bar{Z}_L \quad \rightarrow 4.2.i$$

$$\bar{E}_2 = \bar{I}_2 \bar{Z}_2 + \bar{I}_L \bar{Z}_L$$

$$= I_2 Z_2 + (I_1 + I_2) Z_L \quad \rightarrow 4.2.ii$$

Subtract 4.2.i & 4.2.ii

$$\bar{E}_1 - \bar{E}_2 = \bar{I}_1 \bar{Z}_1 - \bar{I}_2 \bar{Z}_2 \quad \rightarrow 4.2.iii$$

On no load

$$\bar{I}_1 = -\bar{I}_2 = \frac{\bar{E}_1 - \bar{E}_2}{\bar{Z}_1 + \bar{Z}_2}$$

Short circuit

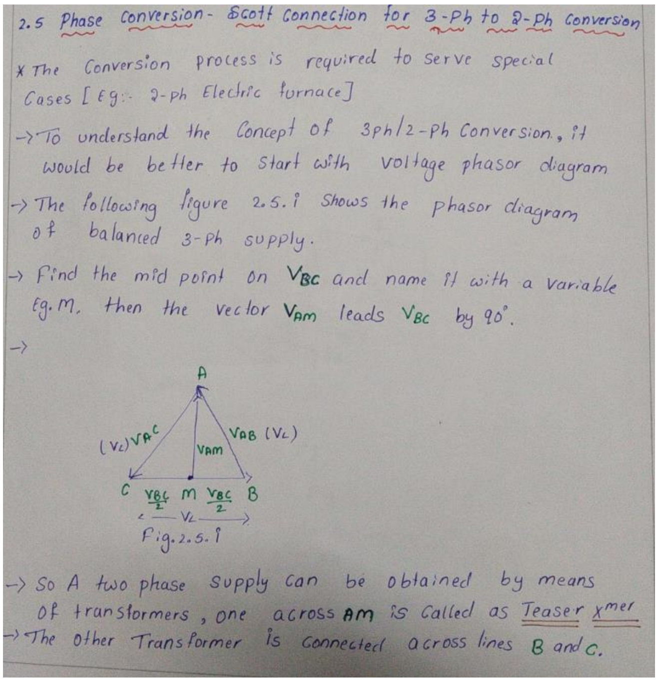
$$\bar{I}_1 = \frac{\bar{E}_1}{\bar{Z}_1}$$

$$\bar{I}_2 = \frac{\bar{E}_2}{\bar{Z}_2}$$

On Load

$$I_1 = \frac{(\bar{E}_1 - \bar{E}_2) + \bar{I}_2 \bar{Z}_2}{Z_1}$$

6 a



2.5 Phase Conversion - Scott Connection for 3-Ph to 2-Ph Conversion

* The Conversion process is required to serve special Cases [Eg:- 2-ph Electric furnace]

→ To understand the Concept of 3ph/2-Ph Conversion, it would be better to start with voltage phasor diagram

→ The following figure 2.5.i Shows the phasor diagram of balanced 3-Ph supply.

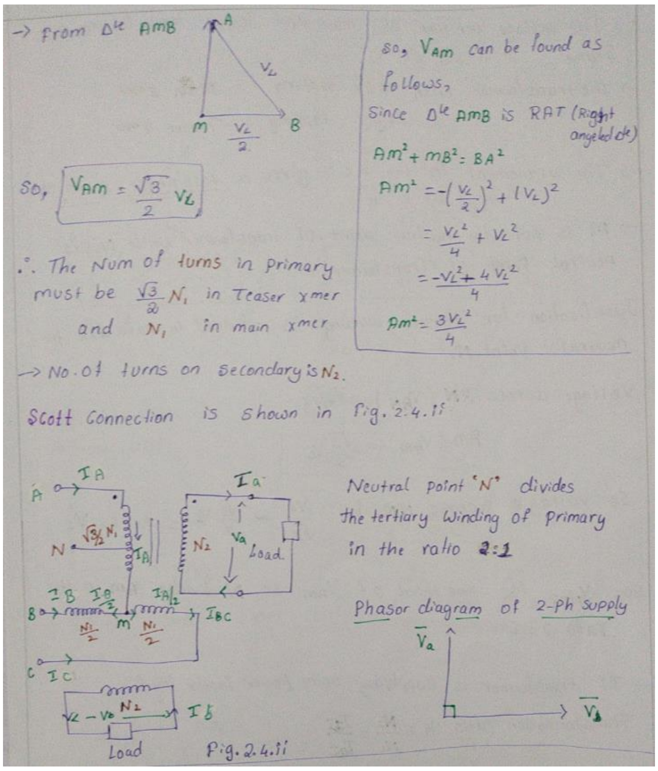
→ Find the mid point on V_{BC} and name it with a variable Eg. M. then the vector V_{AM} leads V_{BC} by 90°.

→

Fig.2.5.i

→ So A two phase supply can be obtained by means of transformers, one across AM is Called as Teaser xmer

→ The other Transformer is connected across lines B and C.


→ From Δ^{le} AmB

So, $\boxed{V_{Am} = \frac{\sqrt{3}}{2} V_L}$

∴ The Num of turns in primary must be $\frac{\sqrt{3}}{2} N_1$ in Teaser xmer and N_1 in main xmer

→ No. of turns on secondary is N_2.

So, V_{Am} can be found as follows,

Since Δ^{le} AmB is RAT (Right angled Δ^{le})

$$Am^2 + mB^2 = BA^2$$

$$Am^2 = -\left(\frac{V_L}{2}\right)^2 + (V_L)^2$$

$$= \frac{V_L^2}{4} + V_L^2$$

$$= \frac{-V_L^2 + 4V_L^2}{4}$$

$$Am^2 = \frac{3V_L^2}{4}$$

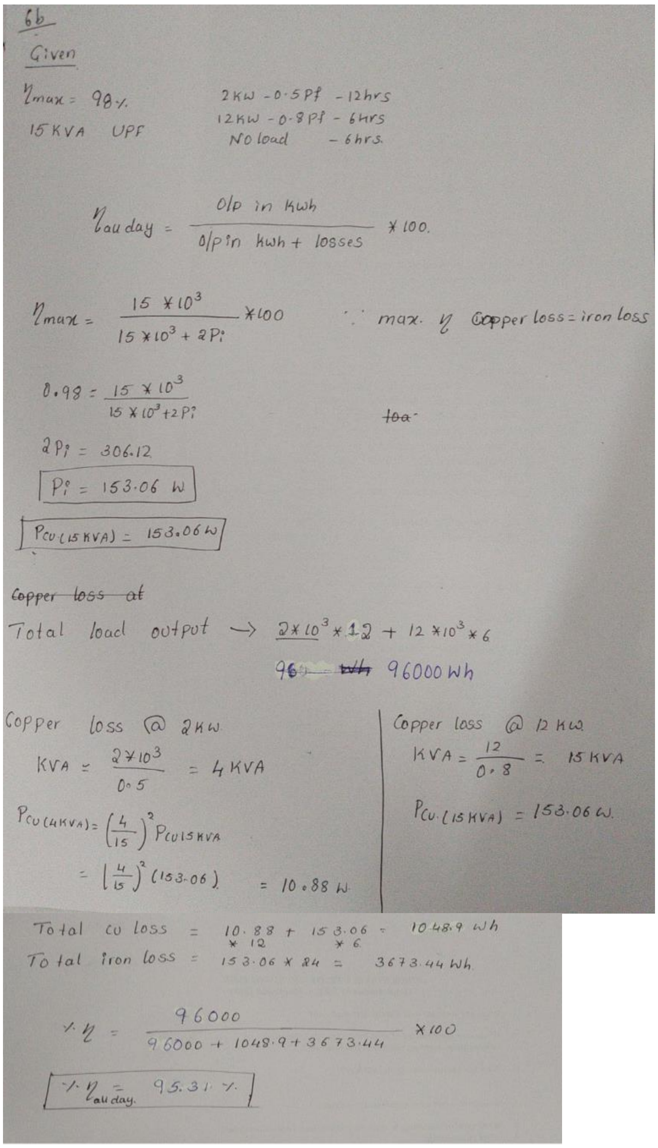
Scott Connection is shown in Fig. 2.4.ii

Fig. 2.4.ii

Neutral point 'N' divides the tertiary Winding of primary in the ratio 2:1

Phasor diagram of 2-Ph supply

6 b


6b

Given

$\eta_{max} = 98\%$

15 KVA UPF

2 KW - 0.5 pf - 12 hrs
12 KW - 0.8 pf - 6 hrs
No load - 6 hrs.

$$\eta_{all\,day} = \frac{\text{o/p in kWh}}{\text{o/p in kWh} + \text{losses}} \times 100.$$

$$\eta_{max} = \frac{15 \times 10^3}{15 \times 10^3 + 2P_i} \times 100$$

∵ max. η Copper loss = iron loss

$$0.98 = \frac{15 \times 10^3}{15 \times 10^3 + 2P_i}$$

~~toa~~

$2P_i = 306.12$

$\boxed{P_i = 153.06\ W}$

$\boxed{P_{cu(15KVA)} = 153.06\ W}$

~~Copper loss at~~

Total load output → $2 \times 10^3 \times 12 + 12 \times 10^3 \times 6$

~~96 Wh~~ 96000 Wh

Copper loss @ 2KW

$$KVA = \frac{2 \times 10^3}{0.5} = 4\ KVA$$

$$P_{cu(4KVA)} = \left(\frac{4}{15}\right)^2 P_{cu15KVA}$$

$$= \left(\frac{4}{15}\right)^2 (153.06) = 10.88\ W$$

Copper loss @ 12 KW

$$KVA = \frac{12}{0.8} = 15\ KVA$$

$$P_{cu(15KVA)} = 153.06\ W.$$

Total cu loss = $10.88 \times 12 + 153.06 \times 6$ = 1048.9 Wh

Total iron loss = 153.06×24 = 3673.44 Wh

$$\%\eta = \frac{96000}{96000 + 1048.9 + 3673.44} \times 100$$

$\boxed{\%\eta_{all\,day} = 95.31\ \%}$

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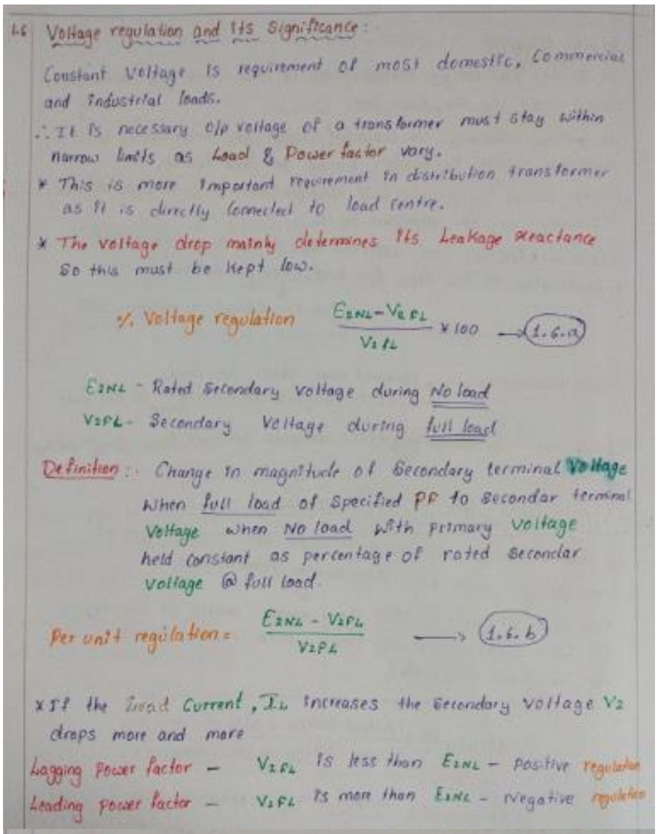

1.6 Voltage regulation and its significance:

Constant voltage is requirement of most domestic, commercial and industrial loads.

∴ It is necessary o/p voltage of a transformer must stay within narrow limits as Load & Power factor vary.

* This is more important requirement in distribution transformer as it is directly connected to load centre.
* The voltage drop mainly determines its Leakage Reactance so this must be kept low.

$$\%\ \text{Voltage regulation} \quad \frac{E_{2NL} - V_{2FL}}{V_{2FL}} \times 100 \longrightarrow \text{(1.6.a)}$$

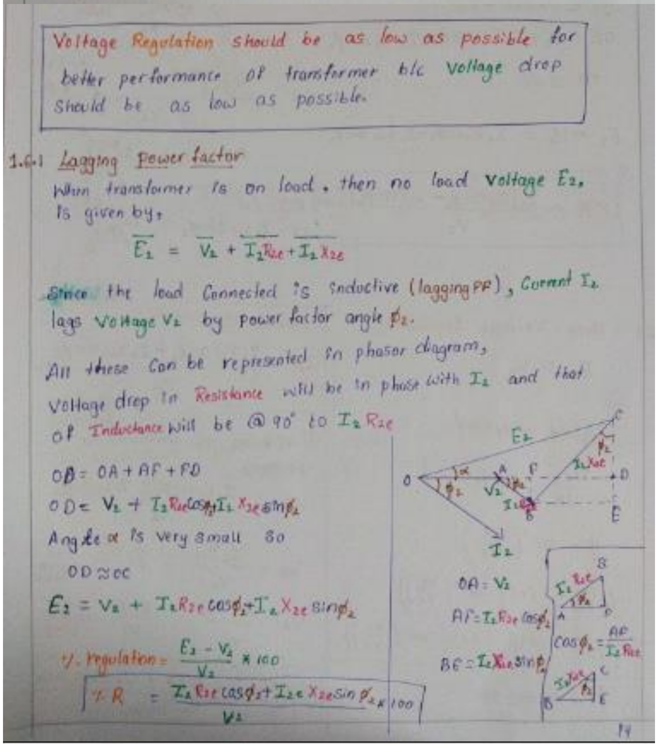
E_{2NL} - Rated secondary voltage during No load
V_{2FL} - Secondary Voltage during full load

Definition: Change in magnitude of Secondary terminal Voltage when full load of specified PF to secondar terminal Voltage when No load with primary voltage held constant as percentage of rated secondar voltage @ full load.

$$\text{Per unit regulation} = \frac{E_{2NL} - V_{2FL}}{V_{2FL}} \longrightarrow \text{(1.6.b)}$$

* If the load Current, I_L increases the secondary voltage V_2 drops more and more

Lagging power factor – V_{2FL} is less than E_{2NL} – positive regulation
Leading power factor – V_{2FL} is more than E_{2NL} – Negative regulation


Voltage Regulation should be as low as possible for better performance of transformer b/c voltage drop should be as low as possible.

1.6.1 Lagging power factor

When transformer is on load, then no load voltage E_2, is given by,

$$\overline{E_2} = \overline{V_2} + \overline{I_2 R_{2e}} + \overline{I_2 X_{2e}}$$

Since the load connected is inductive (lagging PF), Current I_2 lags voltage V_2 by power factor angle ϕ_2.

All these can be represented in phasor diagram, voltage drop in Resistance will be in phase with I_2 and that of Inductance will be @ 90° to $I_2 R_{2e}$

$OD = OA + AF + FD$

$OD = V_2 + I_2 R_{2e}\cos\phi_2 + I_2 X_{2e}\sin\phi_2$

Angle α is very small so

$OD \approx OC$

$$E_2 = V_2 + I_2 R_{2e}\cos\phi_2 + I_2 X_{2e}\sin\phi_2$$

$$\%\ \text{regulation} = \frac{E_2 - V_2}{V_2} \times 100$$

$$\boxed{\%R = \frac{I_2 R_{2e}\cos\phi_2 + I_{2e} X_{2e}\sin\phi_2}{V_2} \times 100}$$

$OA = V_2$

$AF = I_2 R_{2e}\cos\phi_2$

$BE = I_2 X_{2e}\sin\phi_2$

$\cos\phi_2 = \frac{AF}{I_2 R_{2e}}$

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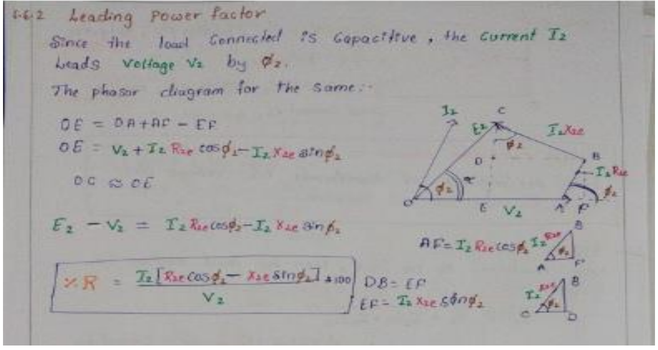
1.6.2 Leading power factor

Since the load connected is capacitive, the current I_2 leads voltage V_2 by ϕ_2.

The phasor diagram for the same:-

$OE = OA + AF - EF$

$OE = V_2 + I_2 R_{2e}\cos\phi_2 - I_2 X_{2e}\sin\phi_2$

$OC \approx OE$

$$E_2 - V_2 = I_2 R_{2e}\cos\phi_2 - I_2 X_{2e}\sin\phi_2$$

$$\boxed{\%R = \frac{I_2[R_{2e}\cos\phi_2 - X_{2e}\sin\phi_2]}{V_2} \times 100}$$

$AF = I_2 R_{2e}\cos\phi_2$

$DB = EF$

$EF = I_2 X_{2e}\sin\phi_2$